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(54) **FUEL MANAGEMENT SYSTEM FOR VARIABLE ETHANOL OCTANE ENHANCEMENT OF GASOLINE ENGINES**

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(Continued)

(51) **Int. Cl.**
F02M 25/14 (2006.01)
F02B 47/04 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC . ***F02B 47/04*** (2013.01); ***F02B 7/00*** (2013.01); ***F02B 17/005*** (2013.01); ***F02B 47/00*** (2013.01);
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See application file for complete search history.

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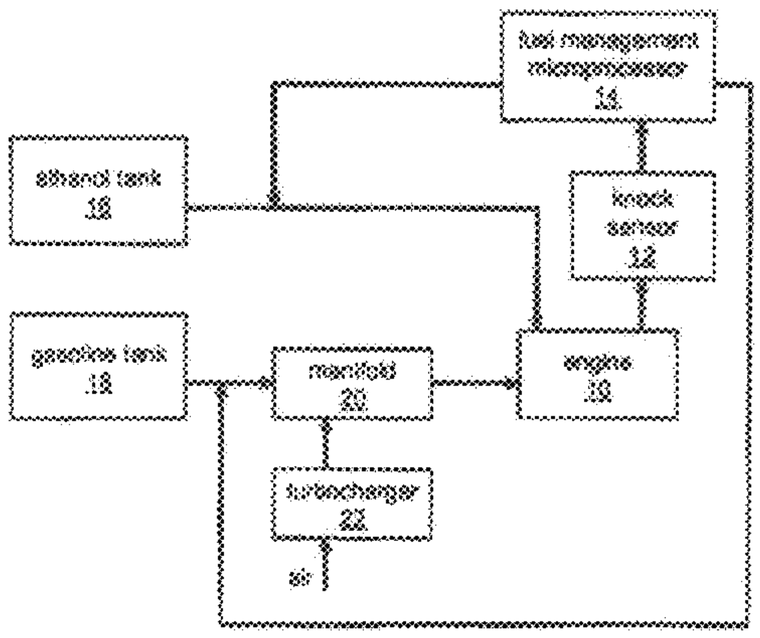
(57) **ABSTRACT**

Fuel management system for efficient operation of a spark ignition gasoline engine. Injectors inject an anti-knock agent such as ethanol directly into a cylinder of the engine. A fuel management microprocessor system controls injection of the anti-knock agent so as to control knock and minimize that amount of the anti-knock agent that is used in a drive cycle. It is preferred that the anti-knock agent is ethanol. The use of ethanol can be further minimized by injection in a non-uniform manner within a cylinder. The ethanol injection suppresses knock so that higher compression ratio and/or engine downsizing from increased turbocharging or supercharging can be used to increase the efficiency or the engine.

31 Claims, 3 Drawing Sheets



Related U.S. Application Data

continuation of application No. 13/629,836, filed on Sep. 28, 2012, now Pat. No. 8,522,746, and a continuation of application No. 13/368,382, filed on Feb. 8, 2012, now Pat. No. 8,302,580, and a continuation of application No. 13/282,787, filed on Oct. 27, 2011, now Pat. No. 8,146,568, and a continuation of application No. 13/117,448, filed on May 27, 2011, now Pat. No. 8,069,839, and a continuation of application No. 12/815,842, filed on Jun. 15, 2010, now Pat. No. 7,971,572, and a continuation of application No. 12/329,729, filed on Dec. 8, 2008, now Pat. No. 7,762,233, and a continuation of application No. 11/840,719, filed on Aug. 17, 2007, now Pat. No. 7,740,004, and a continuation of application No. 10/991,774, filed on Nov. 18, 2004, now Pat. No. 7,314,033.

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F02M 25/00	(2006.01)

(52) **U.S. Cl.**

CPC ***F02B 51/00*** (2013.01); ***F02D 19/08*** (2013.01); ***F02D 19/081*** (2013.01); ***F02D 41/0025*** (2013.01); ***F02M 25/00*** (2013.01); ***F02M 25/14*** (2013.01); *Y02T 10/148* (2013.01)

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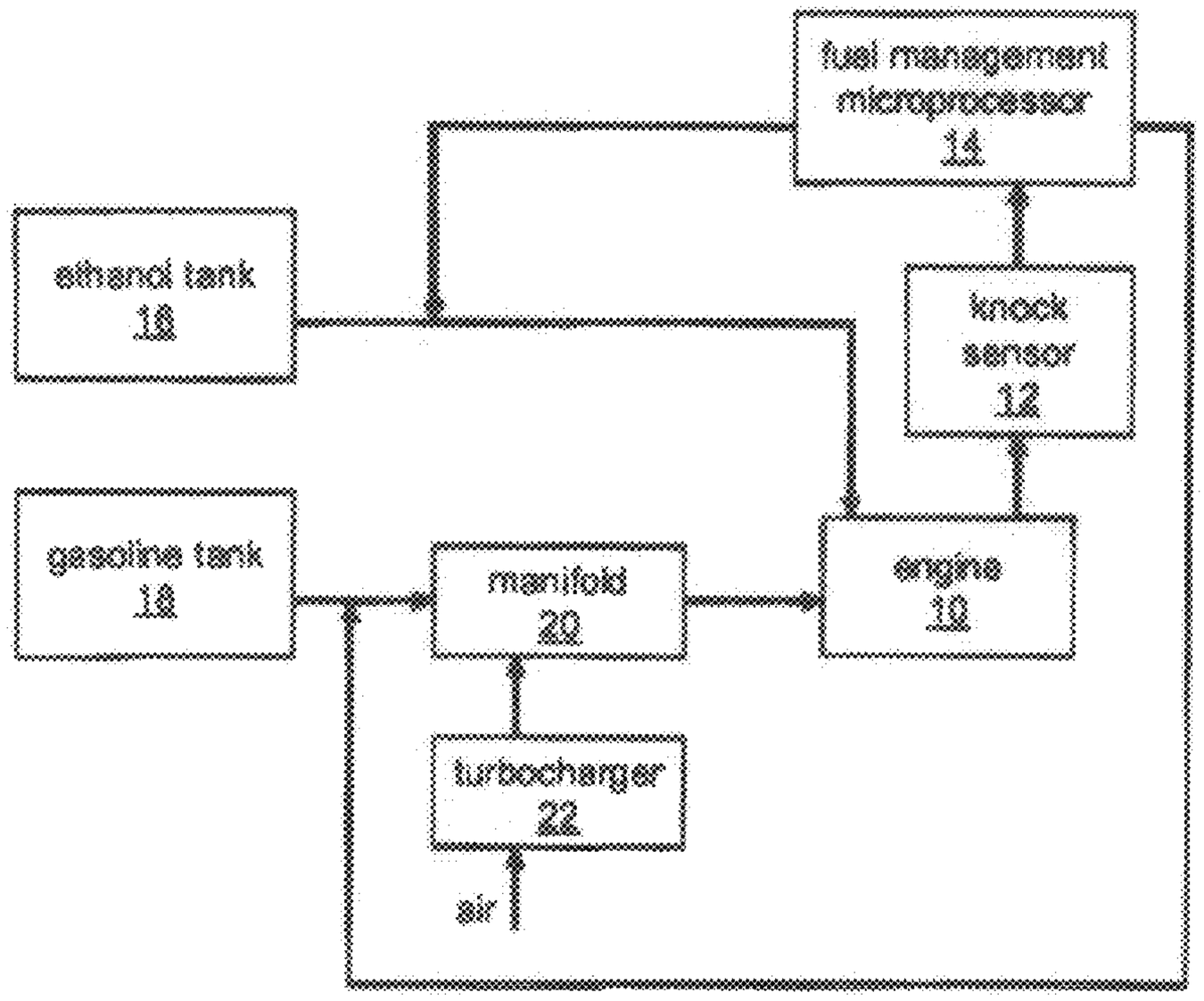
fuel management microprocessor 14
ethanol tank 16
knock sensor 12
gasoline tank 18
manifold 20
engine 10
turbocharger 22
air

FIG. 1

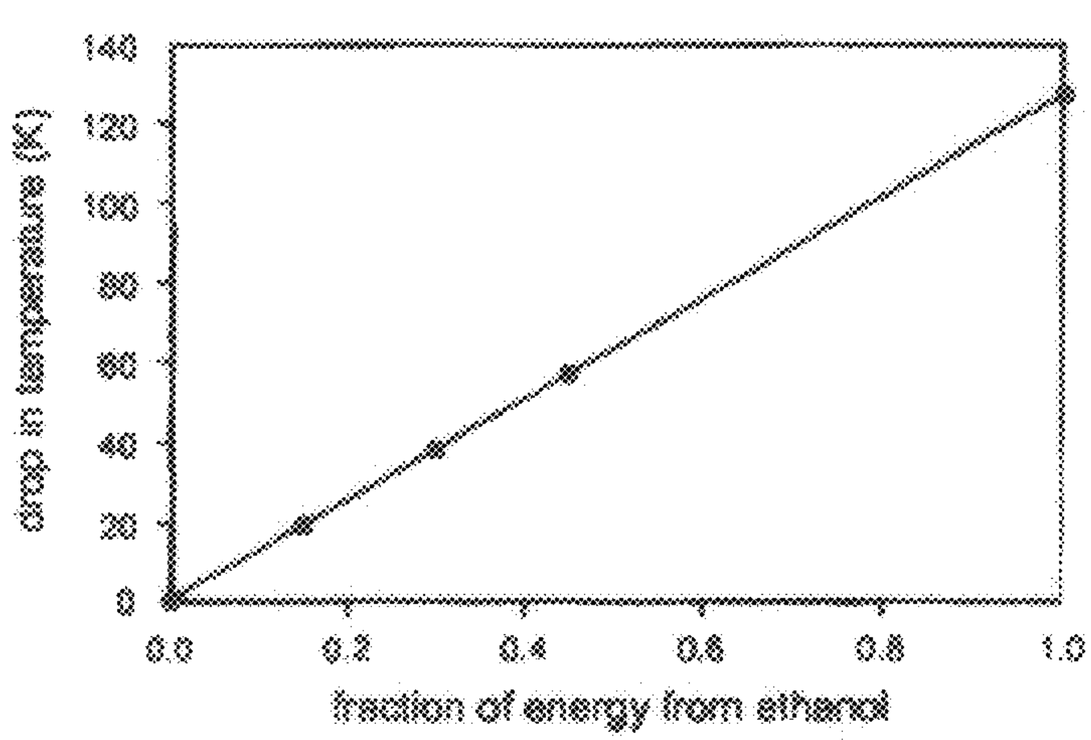
drop in temperature (K)
140
120
100
80
60
40
20
0
0.0
0.2
0.4
0.6
0.8
1.0
fraction of energy from ethanol

FIG. 2

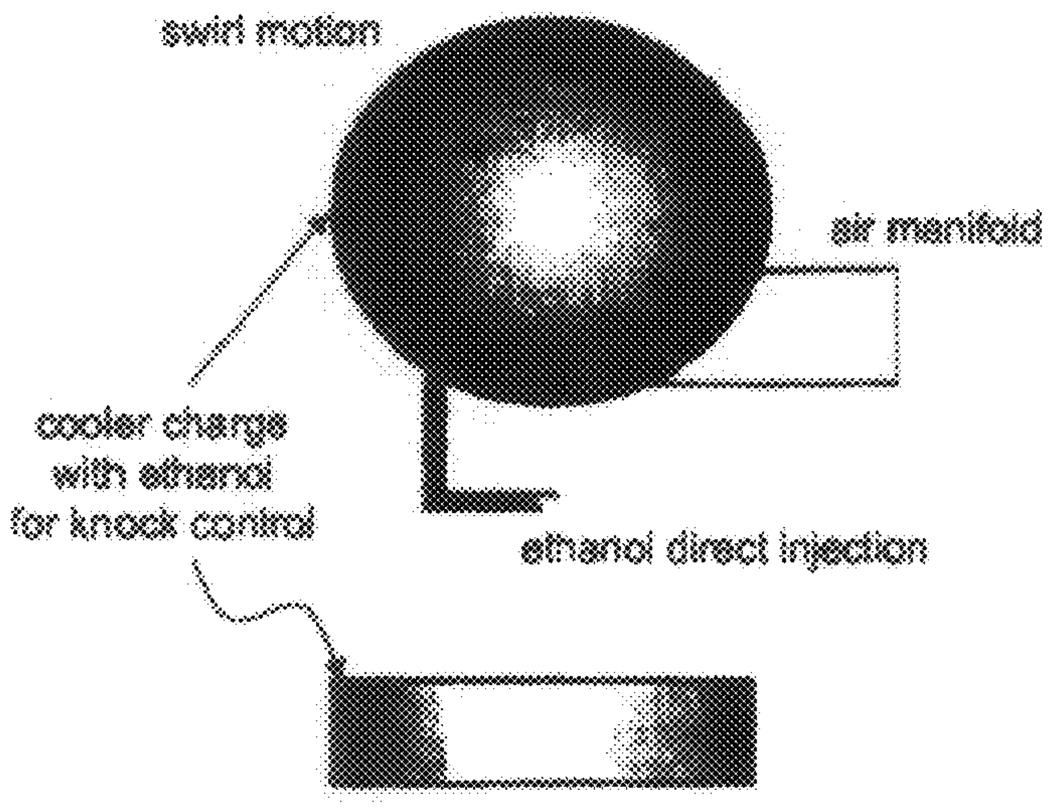
swirl motion
air manifold
cooler charge
with ethanol
for knock control
ethanol direct injection

FIG. 3

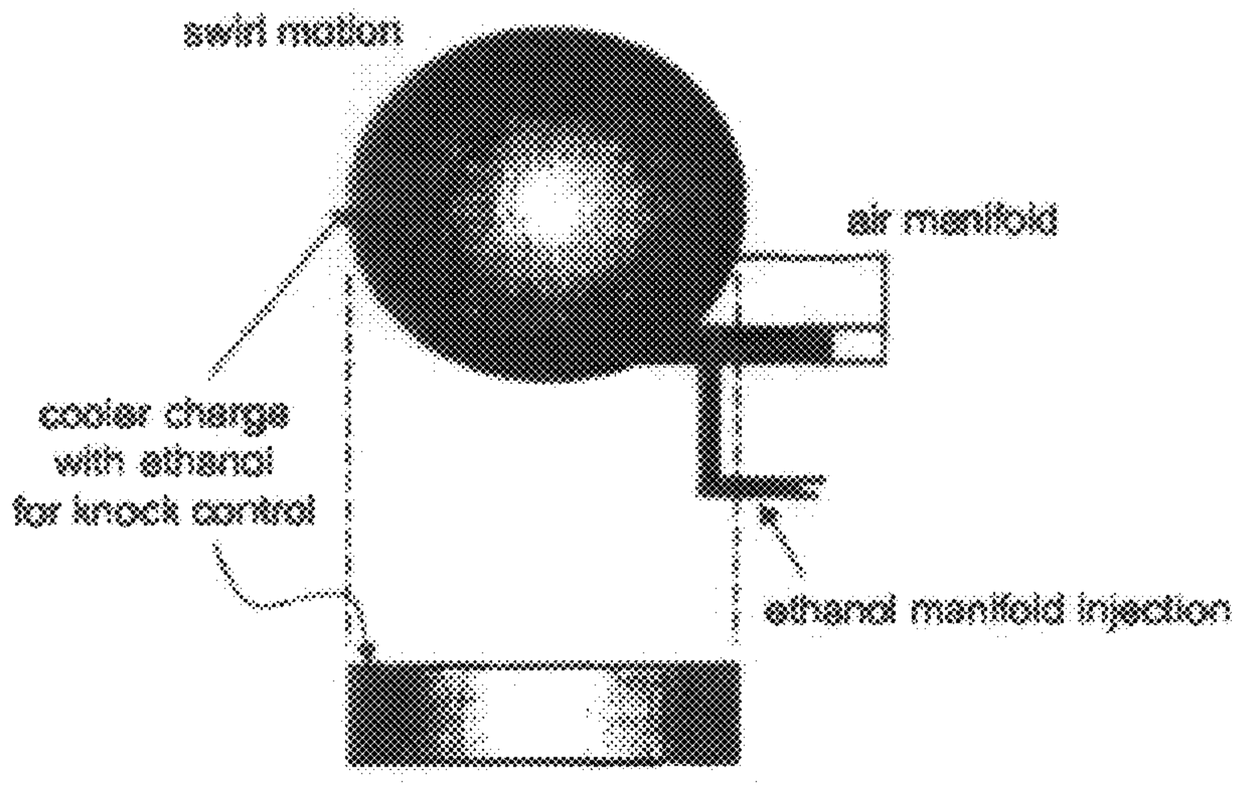
swirl motion
air manifold
cooler charge
with ethanol
for knock control
ethanol manifold injection

FIG. 4

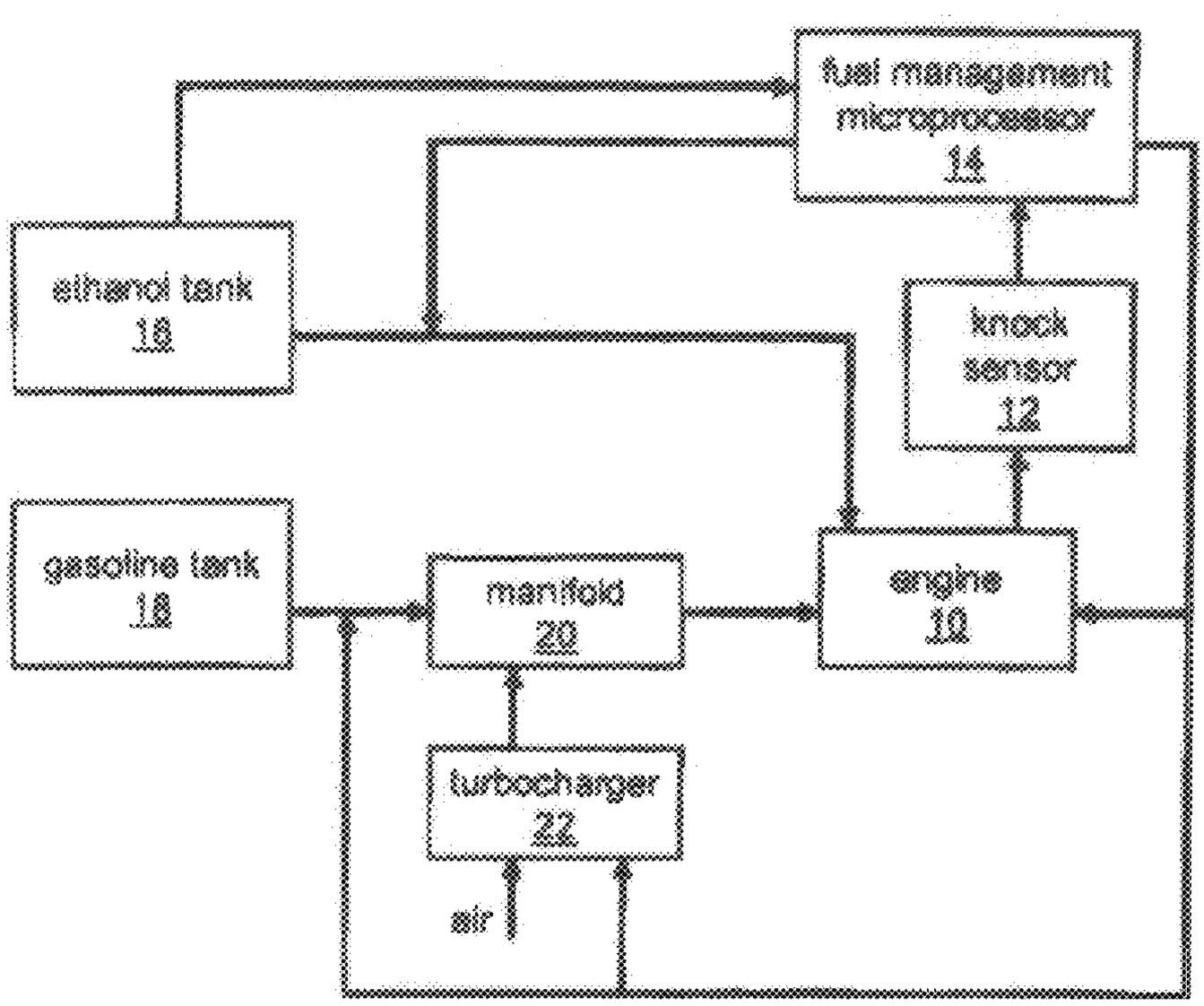
fuel management microprocessor 14
ethanol tank 16
knock sensor 12
gasoline tank 18
manifold 20
engine 10
turbocharger 22
air

FIG. 5

FUEL MANAGEMENT SYSTEM FOR VARIABLE ETHANOL OCTANE ENHANCEMENT OF GASOLINE ENGINES

This application is a continuation of U.S. patent application Ser. No. 14/249,806 filed on Apr. 10, 2014, which is a continuation of U.S. patent application Ser. No. 13/956,498 filed on Aug. 1, 2013, which is now issued as U.S. Pat. No. 8,733,321, which is a continuation of U.S. patent application Ser. No. 13/629,836 filed on Sep. 28, 2012 which is now issued as U.S. Pat. No. 8,522,746, which is a continuation of U.S. patent application Ser. No. 13/368,382 filed on Feb. 8, 2012, which is now issued as U.S. Pat. No. 8,302,580, which is a continuation of U.S. patent application Ser. No. 13/282,787 filed Oct. 27, 2011, which is now issued as U.S. Pat. No. 8,146,568, which is a continuation of U.S. patent application Ser. No. 13/117,448 filed May 27, 2011, which is now issued as U.S. Pat. No. 8,069,839, which is a continuation of U.S. patent application Ser. No. 12/815,842, filed Jun. 15, 2010, which is now issued as U.S. Pat. No. 7,971,572, which is a continuation of U.S. patent application Ser. No. 12/329,729 filed on Dec. 8, 2008, which is now issued as U.S. Pat. No. 7,762,233, which is a continuation of U.S. patent application Ser. No. 11,840,719 filed on Aug. 17, 2007, which is now issued as U.S. Pat. No. 7,740,004, which is a continuation of U.S. patent application Ser. No. 10/991,774, which is now issued as U.S. Pat. No. 7,314,033.

BACKGROUND

This invention relates to spark ignition gasoline engines utilizing an antiknock agent which is a liquid fuel with a higher octane number than gasoline such as ethanol to improve engine efficiency.

It is known that the efficiency of spark ignition (SI) gasoline engines can be increased by high compression ratio operation and particularly by engine downsizing. The engine downsizing is made possible by the use of substantial pressure boosting from either turbocharging or supercharging. Such pressure boosting makes it possible to obtain the same performance in a significantly smaller engine. See, J. Stokes, et al., "A Gasoline Engine Concept For Improved Fuel Economy The Lean-Boost System," SAE Paper 2001-01-2902. The use of these techniques to increase engine efficiency, however, is limited by the onset of engine knock. Knock is the undesired detonation of fuel and can severely damage an engine. If knock can be prevented, then high compression ratio operation and high pressure boosting can be used to increase engine efficiency by up to twenty-five percent.

Octane number represents the resistance of a fuel to knocking but the use of higher octane gasoline only modestly alleviates the tendency to knock. For example, the difference between regular and premium gasoline is typically six octane numbers. That is significantly less than is needed to realize fully the efficiency benefits of high compression ratio or turbocharged operation. There is thus a need for a practical means for achieving a much higher level of octane enhancement so that engines can be operated much more efficiently.

It is known to replace a portion of gasoline with small amount of ethanol added at the refinery. Ethanol has a blending octane number (ON) of 110 (versus 95 for premium gasoline) (see J. B. Heywood, "Internal Combustion Engine Fundamentals," McGraw Hill, 1988, p. 477) and is also attractive because it is a renewable energy, biomass-derived fuel, but the small amounts of ethanol that have heretofore been added to gasoline have had a relatively small impact on

engine performance. Ethanol is much more expensive than gasoline and the amount of ethanol that is readily available is much smaller than that of gasoline because of the relatively limited amount of biomass that is available for its production. An object of the present invention is to minimize the amount of ethanol or other antiknock agent that is used to achieve a given level of engine efficiency increase. By restricting the use of ethanol to the relatively small fraction of time in an operating cycle when it is needed to prevent knock in a higher load regime and by minimizing its use at these times, the amount of ethanol that is required can be limited to a relatively small fraction of the fuel used by the spark ignition gasoline engine.

SUMMARY

In one aspect, the invention is a fuel management system for efficient operation of a spark ignition gasoline engine including a source of an antiknock agent such as ethanol. An injector directly injects the ethanol into a cylinder of the engine and a fuel management system controls injection of the antiknock agent into the cylinder to control knock with minimum use of the antiknock agent. A preferred antiknock agent is ethanol. Ethanol has a high heat of vaporization so that there is substantial cooling of the air-fuel charge to the cylinder when it is injected directly into the engine. This cooling effect reduces the octane requirement of the engine by a considerable amount in addition to the improvement in knock resistance from the relatively high octane number of ethanol. Methanol, tertiary butyl alcohol, MTBE, ETBE, and TAME may also be used. Wherever ethanol is used herein it is to be understood that other antiknock agents are contemplated.

The fuel management system uses a fuel management control system that may use a microprocessor that operates in an open loop fashion on a predetermined correlation between octane number enhancement and fraction of fuel provided by the antiknock agent. To conserve the ethanol, it is preferred that it be added only during portions of a drive cycle requiring knock resistance and that its use be minimized during these times. Alternatively, the gasoline engine may include a knock sensor that provides a feedback signal to a fuel management microprocessor system to minimize the amount of the ethanol added to prevent knock in a closed loop fashion.

In one embodiment the injectors stratify the ethanol to provide non-uniform deposition within a cylinder. For example, the ethanol may be injected proximate to the cylinder walls and swirl can create a ring of ethanol near the walls.

In another embodiment of this aspect of the invention, the system includes a measure of the amount of the antiknock agent such as ethanol in the source containing the antiknock agent to control turbocharging, supercharging or spark retard when the amount of ethanol is low.

The direct injection of ethanol provides substantially a 13° C. drop in temperature for every ten percent of fuel energy provided by ethanol. An instantaneous octane enhancement of at least 4 octane numbers may be obtained for every 20 percent of the engine's energy coming form the ethanol.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of one embodiment of the invention disclosed herein.

FIG. **2** is a graph of the drop in temperature within a cylinder as a function of the fraction of energy provided by ethanol.

FIG. **3** is a schematic illustration of the stratification of cooler ethanol charge using direct injection and swirl motion for achieving thermal stratification.

FIG. **4** is a schematic illustration showing ethanol stratified in an inlet manifold.

FIG. **5** is a block diagram of an embodiment of the invention in which the fuel management microprocessor is used to control a turbocharger and spark retard based upon the amount of ethanol in a fuel tank.

DETAILED DESCRIPTION

With reference first to FIG. **1**, a spark ignition gasoline engine **10** includes a knock sensor **12** and a fuel management microprocessor system **14**. The fuel management microprocessor system **14** controls the direct injection of an antiknock agent such as ethanol from an ethanol tank **16**. The fuel management microprocessor system **14** also controls the delivery of gasoline from a gasoline tank **18** into engine manifold **20**. A turbocharger **22** is provided to improve the torque and power density of the engine **10**. The amount of ethanol injection is dictated either by a predetermined correlation between octane number enhancement and fraction of fuel that is provided by ethanol in an open loop system or by a closed loop control system that uses a signal from the knock sensor **12** as an input to the fuel management microprocessor **14**. In both situations, the fuel management processor **14** will minimize the amount of ethanol added to a cylinder while still preventing knock. It is also contemplated that the fuel management microprocessor system **14** could provide a combination of open and closed loop control.

As show in FIG. **1** it is preferred that ethanol be directly injected into the engine **10**. Direct injection substantially increases the benefits of ethanol addition and decreases the required amount of ethanol. Recent advances in fuel injector and electronic control technology allows fuel injection directly into a spark ignition engine rather than into the manifold **20**. Because ethanol has a high heat of vaporization there will be substantial cooling when it is directly injected into the engine **10**. This cooling effect further increases knock resistance by a considerable amount. In the embodiment of FIG. **1** port fuel injection of the gasoline in which the gasoline is injected into the manifold rather than directly injected into the cylinder is preferred because it is advantageous in obtaining good air/fuel mixing and combustion stability that are difficult to obtain with direct injection.

Ethanol has a heat of vaporization of 840 kJ/kg, while the heat of vaporization of gasoline is about 350 kJ/kg. The attractiveness of ethanol increases when compared with gasoline on an energy basis, since the lower heating value of ethanol is 26.9 MJ/kg while for gasoline it is about 44 MJ/kg. Thus, the heat of vaporization per Joule of combustion energy is 0.031 for ethanol and 0.008 for gasoline. That is, for equal amounts of energy the required heat of vaporization of ethanol is about four times higher than that of gasoline. The ratio of the heat of vaporization per unit air required for stoichiometric combustion is about 94 kJ/kg of air for ethanol and 24 kJ/kg of air for gasoline, or a factor of four smaller. Thus, the net effect of cooling the air charge is about four times lower for gasoline than for ethanol (for stoichiometric mixtures wherein the amount of air contains oxygen that is just sufficient to combust all of the fuel).

In the case of ethanol direct injection according to one aspect of the invention, the charge is directly cooled. The amount of cooling due to direct injection of ethanol is shown in FIG. **2**. It is assumed that the air/fuel mixture is stoichiometric without exhaust gas recirculation (EGR), and that

gasoline makes up the rest of the fuel. It is further assumed that only the ethanol contributes to charge cooling. Gasoline is vaporized in the inlet manifold and does not contribute to cylinder charge cooling. The direct ethanol injection provides about I3° C. of cooling for each 10% of the fuel energy provided by ethanol. (It is also possible to use direct injection of gasoline as well as direct injection of ethanol. However, under certain conditions there can be combustion stability issues.

The temperature decrement because of the vaporization energy of the ethanol decreases with lean operation and with EGR, as the thermal capacity of the cylinder charge increases. If the engine operates at twice the stoichiometric air/fuel ratio, the numbers indicated in FIG. **2** decrease by about a factor of 2 (the contribution of the ethanol itself and the gasoline is relatively modest). Similarly, for a 20% EGR rate, the cooling effect of the ethanol decreases by about 25%.

The octane enhancement effect can be estimated from the data in FIG. **2**. Direct injection of gasoline results in approximately a five octane number decrease in the octane number required by the engine, as discussed by Stokes, et al. Thus the contribution is about five octane numbers per 30 K drop in charge temperature. As ethanol can decrease the charge temperature by about 120 K, then the decrease in octane number required by the engine due to the drop in temperature, for 100% ethanol, is twenty octane numbers. Thus, when 100% of the fuel is provided by ethanol, the octane number enhancement is approximately thirty-five octane numbers with a twenty octane number enhancement coming from direct injection cooling and a fifteen octane number enhancement coming from the octane number of ethanol. From the above considerations, it can be projected that even if the octane enhancement from direct cooling is significantly lower, a total octane number enhancement of at least 4 octane numbers should be achievable for every 20% of the total fuel energy that is provided by ethanol.

Alternatively the ethanol and gasoline can be mixed together and then port injected through a single injector per cylinder, thereby decreasing the number of injectors that would be used. However, the air charge cooling benefit from ethanol would be lost.

Alternatively the ethanol and gasoline can be mixed together and then port fuel injected using a single injector per cylinder, thereby decreasing the number of injectors that would be used. However, the substantial air charge cooling benefit from ethanol would be lost. The volume of fuel between the mixing point and the port fuel injector should be minimized in order to meet the demanding dynamic octane-enhancement requirements of the engine.

Relatively precise determinations of the actual amount of octane enhancement from given amounts of direct ethanol injection can be obtained from laboratory and vehicle tests in addition to detailed calculations. These correlations can be used by the fuel management microprocessor system **14**.

An additional benefit of using ethanol for octane enhancement is the ability to use it in a mixture with water. Such a mixture can eliminate the need for the costly and energy consuming water removal step in producing pure ethanol that must be employed when ethanol is added to gasoline at a refinery. Moreover, the water provides an additional cooling (due to vaporization) that further increases engine knock resistance. In contrast the present use of ethanol as an additive to gasoline at the refinery requires that the water be removed from the ethanol.

Since unlike gasoline, ethanol is not a good lubricant and the ethanol fuel injector can stick and not open, it is desirable

to add a lubricant to the ethanol. The lubricant will also denature the ethanol and make it unattractive for human consumption.

Further decreases in the required ethanol for a given amount of octane enhancement can be achieved with stratification (non-uniform deposition) of the ethanol addition. Direct injection can be used to place the ethanol near the walls of the cylinder where the need for knock reduction is greatest. The direct injection may be used in combination with swirl. This stratification of the ethanol in the engine further reduces the amount of ethanol needed to obtain a given amount of octane enhancement. Because only the ethanol is directly injected and because it is stratified both by the injection process and by thermal centrifugation, the ignition stability issues associated with gasoline direct injection (GDI) can be avoided.

It is preferred that ethanol be added to those regions that make up the end-gas and are prone to auto-ignition. These regions are near the walls of the cylinder. Since the end-gas contains on the order of 25% of the fuel, substantial decrements in the required amounts of ethanol can be achieved by stratifying the ethanol.

In the case of the engine **10** having substantial organized motion (such as swirl), the cooling will result in forces that thermally stratify the discharge (centrifugal separation of the regions at different density due to different temperatures). The effect of ethanol addition is to increase gas density since the temperature is decreased. With swirl the ethanol mixture will automatically move to the zone where the end-gas is, and thus increase the anti-knock effectiveness of the injected ethanol. The swirl motion is not affected much by the compression stroke and thus survives better than tumble-like motion that drives turbulence towards top-dead-center (TDC) and then dissipates. It should be pointed out that relatively modest swirls result in large separating (centrifugal) forces. A 3 m/s swirl motion in a 5 cm radius cylinder generates accelerations of about 200 m/s^2, or about 20 g's.

FIG. **3** illustrates ethanol direct injection and swirl motion for achieving thermal stratification. Ethanol is predominantly on an outside region which is the end-gas region. FIG. **4** illustrates a possible stratification of the ethanol in an inlet manifold with swirl motion and thermal centrifugation maintaining stratification in the cylinder. In this case of port injection of ethanol, however, the advantage of substantial charge cooling may be lost.

With reference again to FIG. **2**, the effect of ethanol addition all the way up to 100% ethanol injection is shown. At the point that the engine is 100% direct ethanol injected, there may be issues of engine stability when operating with only stratified ethanol injection that need to be addressed. In the case of stratified operation it may also be advantageous to stratify the injection of gasoline in order to provide a relatively uniform equivalence ratio across the cylinder (and therefore lower concentrations of gasoline in the regions where the ethanol is injected). This situation can be achieved, as indicated in FIG. **4**, by placing fuel in the region of the inlet manifold that is void of ethanol.

The ethanol used in the invention can either be contained in a separate tank from the gasoline or may be separated from a gasoline/ethanol mixture stored in one tank.

The instantaneous ethanol injection requirement and total ethanol consumption over a drive cycle can be estimated from information about the drive cycle and the increase in torque (and thus increase in compression ratio engine power density, and capability for downsizing) that is desired. A plot of the amount of operating time spent at various values of torque and engine speed in FTP and US06 drive cycles can be used. It is necessary to enhance the octane number at each point in the drive cycle where the torque is greater than permitted for knock free operation with gasoline alone. The amount of octane enhancement that is required is determined by the torque level.

A rough illustrative calculation shows that only a small amount of ethanol might be needed over the drive cycle. Assume that it is desired to increase the maximum torque level by a factor of two relative to what is possible without direct injection ethanol octane enhancement. Information about the operating time for the combined FTP and US06 cycles shows that approximately only 10 percent of the time is spent at torque levels above 0.5 maximum torque and less than 1 percent of the time is spent above 0.9 maximum torque. Conservatively assuming that 100% ethanol addition is needed at maximum torque and that the energy fraction of ethanol addition that is required to prevent knock decreases linearly to zero at 50 percent of maximum torque, the energy fraction provided by ethanol is about 30 percent. During a drive cycle about 20 percent of the total fuel energy is consumed at greater than 50 percent of maximum torque since during the 10 percent of the time that the engine is operated in this regime, the amount of fuel consumed is about twice that which is consumed below 50 percent of maximum torque. The amount of ethanol energy consumed during the drive cycle is thus roughly around 6 percent (30 percent×0.2) of the total fuel energy.

In this case then, although 100% ethanol addition was needed at the highest value of torque, only 6% addition was needed averaged over the drive cycle. The ethanol is much more effectively used by varying the level of addition according to the needs of the drive cycle.

Because of the lower heat of combustion of ethanol, the required amount of ethanol would be about 9% of the weight of the gasoline fuel or about 9% of the volume (since the densities of ethanol and gasoline are comparable). A separate tank with a capacity of about 1.8 gallons would then be required in automobiles with twenty gallon gasoline tanks. The stored ethanol content would be about 9% of that of gasoline by weight, a number not too different from present-day reformulated gasoline. Stratification of the ethanol addition could reduce this amount by more than a factor of two. An on-line ethanol distillation system might alternatively be employed but would entail elimination or reduction of the increase torque and power available from turbocharging.

Because of the relatively small amount of ethanol and present lack of an ethanol fueling infrastructure, it is important that the ethanol vehicle be operable if there is no ethanol on the vehicle. The engine system can be designed such that although the torque and power benefits would be lower when ethanol is not available, the vehicle could still be operable by reducing or eliminating turbocharging capability and/or by increasing spark retard so as to avoid knock. As shown in FIG. **5**, the fuel management microprocessor system **14** uses ethanol fuel level in the ethanol tank **16** as an input to control the turbocharger **22** (or supercharger or spark retard, not shown). As an example, with on-demand ethanol octane enhancement, a 4-cylinder engine can produce in the range of 280 horsepower with appropriate turbocharging or supercharging but could also be drivable with an engine power of 140 horsepower without the use of ethanol according to the invention.

The impact of a small amount of ethanol upon fuel efficiency through use in a higher efficiency engine can greatly increase the energy value of the ethanol. For example, gasoline consumption could be reduced by 20% due to higher efficiency engine operation from use of a high compression ratio, strongly turbocharged operation and substantial engine

downsizing. The energy value of the ethanol, including its value in direct replacement of gasoline (5% of the energy of the gasoline), is thus roughly equal to 25% of the gasoline that would have been used in a less efficient engine without any ethanol. The 5% gasoline equivalent energy value of ethanol has thus been leveraged up to a 25% gasoline equivalent value. Thus, ethanol can cost roughly up to five times that of gasoline on an energy basis and still be economically attractive. The use of ethanol as disclosed herein can be a much greater value use than in other ethanol applications.

Although the above discussion has featured ethanol as an exemplary anti-knock agent, the same approach can be applied to other high octane fuel and fuel additives with high vaporization energies such as methanol (with higher vaporization energy per unit fuel), and other anti-knock agents such as tertiary butyl alcohol, or ethers such as methyl tertiary butyl ether (MTBE), ethyl tertiary butyl ether (ETBE), or tertiary amyl methyl ether (TAME).

It is recognized that modifications and variations of the invention disclosed herein will be apparent to those of ordinary skill in the art and it is intended that all such modifications and variations be included within the scope of the appended claims.

The invention claimed is:

1. A fuel management system for a turbocharged or supercharged spark ignition engine where the fuel management system controls fueling from a first fueling system that directly injects fuel into at least one cylinder as a liquid and increases knock suppression by vaporization cooling and from a second fueling system that injects fuel into a region outside of the cylinder;

and where there is a range of torque where both fueling systems are used at the same value of torque;

and where the fraction of fuel in the cylinder that is introduced by the first fueling system decreases with decreasing torque and the fuel management system controls the change in the fraction of fuel introduced by the first fueling system using closed loop control that utilizes a sensor that detects knock;

and where the fuel management system also employs spark retard so as to reduce the amount of fuel that is introduced into the cylinder by the first fueling system.

2. The fuel management system of claim **1** where the spark retard is employed to as to reduce the amount of fuel that is provided by the first fueling system to zero.

3. The fuel management system of claim **1** where when the torque is increased the increase in the fraction of fuel that is introduced by the first fueling system is minimized while still preventing knock.

4. The fuel management system of claim **1** where without employing the spark retard there is a range of torque in which only the second fueling system is used.

5. The fuel management system of claim **1** where the fuel management system employs the spark retard in response to sensed information and both the sensed information and information about knock are used to control the fuel that is introduced by the first fueling system.

6. The fuel management system of claim **1** where the maximum torque that the engine provides occurs when both the first and second fueling systems are used at the same value of torque.

7. The fuel management system of claim **1** where the only the first fueling system is used at the maximum torque that the engine provides.

8. The fuel management system of claim **1** where only the first fueling system is used when the highest knock resistance is required.

9. The fuel management system of claim **1** where both the first and second fueling system are used when the highest knock resistance is required.

10. The fuel management system of claim **1** where as the torque is increased the increase in the fraction of fuel in the cylinder that is provided by the first fueling system is substantially equal to that needed to prevent knock.

11. The fuel management system of claims **1** or **3** where the fuel management system minimizes the increase in the fraction of fuel in the cylinder that is provided by the first fueling system as torque is increased.

12. The fuel management system of claim **1** where the second fueling system uses port fuel injection.

13. A fuel management system for a spark ignition engine that controls fueling from a first fueling system that directly injects fuel into at least one cylinder as a liquid and increases knock suppression by vaporization cooling and from a second fueling system that provides fuel to the cylinder using port fuel injection;

and where the fuel management system uses information from a sensed parameter to control spark retard so as to decrease the amount of fuel that would otherwise be provided by the first fueling system;

and where the fuel management system uses input that includes input from the sensed parameter and input from knock sensor.

14. The fuel management system of claim **13** where input from the knock sensor is utilized in a closed loop control system that controls the fraction of fuel that is introduced into the first fueling system.

15. The fuel management system of claim **13** where both the first and second fueling systems are used at the same value of torque.

16. The fuel management system of claim **13** where spark retard is employed so as to reduce the use of the first fueling system to zero.

17. The fuel management system of claim **13** where the engine is turbocharged or supercharged and the level of turbocharging or supercharging is reduced so as to decrease the amount of fuel from the first fueling system.

18. The fuel management system of claim **13** where closed loop control with a knock detector is used to increase the relative amount of fuel from the first fueling system as torque is increased.

19. A fuel management system for a turbocharged or supercharged spark ignition engine where the fuel management system controls fueling from a first fueling system that directly injects fuel into at least one cylinder as a liquid and increases knock suppression by vaporization cooling and from a second fueling system that introduces fuel into the cylinder by port fuel injection;

and where during a driving cycle there is a first torque range where both fueling systems are used at the same torque and where the fraction of fuel in the cylinder that is introduced by the first fueling system is increased so as to prevent knock as torque increases;

and where the fuel management system matches the fraction of fuel that is provided by first fueling system with the amount needed to prevent knock at a given value of torque; and

where the fuel management system uses closed loop control that employs a knock detector.

20. The fuel management system of claim **19** where there is a second torque range where only the second fueling system is used and the highest value of torque in the second torque range is lower than at least one value of torque in the first torque range.

21. The fuel management system of claim **19** where the fuel management system minimizes the amount of fuel from the first fueling system while still preventing knock.

22. The fuel management system of claim **19** where the maximum knock resistance required by the engine is in the first torque range.

23. The fuel management system of claim **19** where for the maximum knock resistance required by the engine only the first fueling system is used.

24. A fuel management system for a spark ignition engine that controls fueling from a first fueling system that introduces fuel into at least one cylinder as a liquid and increases knock resistance by vaporization cooling and from a second fueling system;

and where the knock resistance of fuel introduced by the first fueling system is greater than the knock resistance of fuel introduced by the second fueling system;

and where the fuel management system uses information from a sensed parameter to control spark retard so as to decrease the amount of fuel that would otherwise be provided by the first fueling system;

and where the fuel management system uses input that includes input from the sensed parameter and input from knock sensor.

25. The fuel management system of claim **24** where input from the knock sensor is utilized in a closed loop control system that controls the fraction of fuel that is introduced into the first fueling system.

26. The fuel management system of claim **24** where both the first and second fueling systems are used at the same value of torque.

27. The fuel management system of claim **24** where spark retard is employed so as to reduce the use of the first fueling system to zero.

28. The fuel management system of claim **24** where turbocharging or supercharging is used and the level of turbocharging or supercharging is reduced so as to decrease the amount of fuel from the first fueling system.

29. The fuel management system of claim **24** where closed loop control with a knock detector is used to increase the relative amount of fuel firm the first fueling system as torque is increased.

30. The fuel management system of claim **24** where the first fueling system uses direct injection.

31. The fuel management system of claim **24** where the second fueling system uses port fuel injection.

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(12) **INTER PARTES REVIEW CERTIFICATE** (2359th)
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(54) **FUEL MANAGEMENT SYSTEM FOR VARIABLE ETHANOL OCTANE ENHANCEMENT OF GASOLINE ENGINES**

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INTER PARTES REVIEW CERTIFICATE
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AS A RESULT OF THE INTER PARTES REVIEW PROCEEDING, IT HAS BEEN DETERMINED THAT:

Claims **1-6** and **9-22** are cancelled.

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